JCEC
THE JOURNAL OF ENGINEERING AND EXACT SCIENCES

OPEN ACCESS

The Journal of Engineering and Exact Sciences – jCEC, Vol. 09 N. 08 (2023)
journal homepage: https://periodicos.ufv.br/jcec
eISSN: 2527-1075
ISSN: 2446-9416

Study of Stress Distribution in L-Shaped Walls with Openings under Intense Seismic Conditions on Various Soil Types

Article Info:
Article history: Received 2023-08-01 / Accepted 2023-09-14 / Available online 2023-09-14
doi: 10.18540/jcecvl9iss8pp16604-01e

Salem Merabti
ORCID: https://orcid.org/0000-0002-4615-2179
Acoustics and Civil Engineering Laboratory, Faculty of Science and Technology, University of Khemis-Miliana, Algeria
E-mail: s.merabti@univ-dbkm.dz
Salah Bezari
ORCID: https://orcid.org/ 0009-0007-4119-6352
Unité de Recherche Appliquée en Energies Renouvelables URAER, Centre de Développement des Energies Renouvelables CDER, Ghardaïa 47133, Algeria
E-mail: salahbezari@gmail.com

Resumo
Este artigo contribui para aprofundar o nosso conhecimento sobre a distribuição das tensões de compressão, tração e corte em paredes de corte de edifícios médios de betão armado. Estas paredes de corte em forma de L incluem aberturas que podem representar até 50% da área total da parede. Para realizar este estudo, foram efectuadas análises de desempenho sísmico dos edifícios utilizando o software ABAQUS em quatro tipos distintos de solos, submetendo os edifícios a um sismo de alta intensidade. Foram consideradas três espessuras de parede: 15 cm, 20 cm e 25 cm. Os resultados da análise demonstram que a utilização de paredes mais espessas provou ser eficaz na redução das tensões, como esperado, satisfazendo também os requisitos de resistência. Para além disso, o aumento das aberturas até 30% nas paredes de corte permitiu uma redução das tensões de corte. No entanto, é importante notar que as tensões observadas variaram consoante o tipo de solo e a percentagem de aberturas nas paredes.
Palavras-chave: Edifícios. Betão armado. Parede de cisalhamento. Aberturas verticais.

Abstract
This article contributes to deepening our understanding of the distribution of compression, tension, and shear stress in reinforced concrete mid-rise building shear walls. These L-shaped shear walls include openings that can account for up to 50% of the total wall area. To conduct this study, seismic performance analyses of the buildings were carried out using ABAQUS software on four distinct types of soils, subjecting the buildings to a high-intensity earthquake. Three wall thicknesses were considered: 15 cm, 20 cm, and 25 cm. The analysis results demonstrate that the use of thicker walls proved to be effective in reducing stresses, as expected, while also meeting the strength requirements. Furthermore, increasing the openings up to 30% in the shear walls allowed for a reduction in shear stress. However, it is important to note that the observed stresses varied depending on the type of soil and the percentage of openings in the walls.
Keywords: Buildings. Reinforced concrete. Shear wall. Vertical openings.

1. Introduction

The mid-rise reinforced concrete buildings must be constructed on various types of soil. Indeed, the scarcity of available land and rapid urbanization compel engineers to build on different soil types. To ensure the stability of these buildings, various forms of shear walls are used (Liu *et al*., 2023; Zhou *et al*., 2023; Rong *et al*., 2023; Alarcón *et al*., 2023; Xu *et al*., 2023). These walls behave differently based on the wall length, position, thickness, and structure of the building. In general, these walls are employed due to their stiffness, high load-bearing capacity, and significant ductility (Galal *et al*., 2008). When the height-to-length ratio is less than 2, these walls are called short walls, and shear stress typically predominates over flexural stress. On the other hand, when the height-to-length ratio is greater than 2, these walls are referred to as tall walls, and in this case, flexural failure becomes more prominent and significant (ACI 318-19., 2022). However, ASCE 41-17 (2017) standard addresses three distinct categories: shear-controlled walls apply when the height-to-length ratio is less than 1.5. For walls with a ratio between 1.5 and 3, the standard recommends a combined approach of flexure and shear, referred to as flexure-shear-controlled walls. Finally, when the ratio exceeds 3, the primary focus is on flexural resistance, classifying these walls as flexure-controlled in seismic design. Among the different types of shear walls used in reinforced concrete buildings, L-shaped walls are extensively studied. Ugalde and Lopez-Garcia., (2017) examined three tall buildings that experienced an earthquake in Chile in 2010. These buildings were equipped with L-shaped shear walls to reinforce their structure. Despite the earthquake's high intensity, they found that these buildings did not suffer any damage. Similarly, Benbellil *et al.* (2019) compared two L-shaped walls between a numerical model and an experimentally constructed wall. This research showed that the deformation caused by flexure at the base of the L-shaped reinforced concrete shear walls predominated and accounted for approximately 80% of the total deformation. The possibility of increasing the capacity of shear walls is demonstrated by Najm *et al.* (2022) increasing the reinforcement ratio to 3.5% indeed improved ductility by 37% and energy absorption by 38%. Additionally, increasing the compressive strength of concrete to 55 MPa improved ductility by 51% and energy absorption by 38%. Increasing the yield strength of steel sheeting to 380 MPa increased ductility by 66%. Recently, Wang et al. conducted a study on prefabricated shear walls (Wang *et al*., 2022). In this study, dampers were used to connect the shear walls vertically. The walls were subjected to low-cycle axial compression tests, and the results demonstrated that buildings with prefabricated shear walls exhibited good mechanical properties and improved wall ductility. The dampers dissipate energy, thereby enhancing the seismic performance of the building.

The study conducted by Chaouch *et al.* (2015) aimed to evaluate the effect of the thickness of L-shaped shear walls, the wall's length, and the building's height on shear stress. The results showed that reinforced concrete shear walls with 15 floors or fewer should have a minimum length of 10 times their thickness. However, for walls with a thickness greater than 20 cm, their length should exceed 7 times their thickness.

Reinforced concrete buildings braced with shear walls with openings offer several functional advantages, such as the installation of doors, windows, and service ducts. Kim and Lee examined the influence of small openings in shear walls, and their study revealed that small openings had only a minor impact on lateral deformations, whereas larger openings had a more significant effect. However, the shape of the openings also played a significant role in their behavior (Kim and Lee., 2003). Similar results were reported by Berman *et al*. (2005) and Balkaya *et al*. (2004). Sharma and Amin., (2015) studied a building with shear walls containing openings of different sizes. The results showed that the inter-story drift and displacement were influenced by the shape of the opening in addition to its size. Openings in shear walls are subjected to localized high vertical and shear stress around the corners of the openings. The study by Saeed *et al.*, (2022) also examined L-shaped reinforced concrete shear walls with and without openings. The results showed little difference between regular and offset openings. Varma and Kumar studied mid-rise buildings with openings in shear walls. According to their research, the opening width had a greater influence on the building's behavior than its height. They also found that openings close to the edges of the walls

caused larger total displacements than those located in the center of the wall (Varma and Kumar., 2021). Mosoarca studied the effects of offset openings in reinforced concrete shear walls in seismic zones. The theoretical results were confirmed through experimental tests, and the analysis of failure modes contributed to the development of seismic design codes for these walls (Mosoarca., 2014). Alhusban and Parvin conducted a study on reinforced concrete walls strengthened with textile-reinforced mortar (TRM) and openings, subjected to axial load. The results showed a 34% increase for walls with door openings and a 26% increase for those with window openings compared to corresponding control models (Alhusban, A. Parvin., 2022).

Damage to low to mid-rise reinforced concrete buildings during earthquakes is a widely studied topic in the field of civil engineering (Ashim *et al*., 2019). Other works focus on existing buildings, testing them during different major earthquakes with magnitudes of Mw 6.5 and 5.1 (Bessason *et al*., 2016; Romão *et al*., 2013). Major damage has been observed in buildings constructed according to the old code. In contrast, buildings erected following the new code recorded minimal damage. Therefore, adhering to current seismic codes not only preserves buildings but also saves human lives.

In this study, we examine ten-story buildings located in a high-seismicity zone and evaluate the stress in shear walls with different sizes of openings. So far, the influence of openings on stress in shear walls has not been studied for different types of soil. The main objective of this study is to quantify compression, tension, and shear stress and compare them with the stress in buildings braced with shear walls without openings.

2. Building and the variables studied

In this study, we numerically analyze ten-story reinforced concrete buildings with L-shaped walls placed at the four corners of the structure. These walls are equipped with openings at the center of the wall, with a fixed height of 2 m, while the width of the opening was varied. The building consists of five bays on the X-axis (longitudinal) and four bays on the Y-axis of 4.5 meters (transverse). The height of the floors is uniform at 2 m for the entire building. We examine 132 buildings, and the analysis focuses on three main parameters:

- Wall thickness,
- Wall openings,
- Soil type.

The buildings were designed with three wall thicknesses: 15 cm, 20 cm, and 25 cm. Furthermore, we considered that the buildings are constructed on four different types of soils, as indicated in Table 1. Regarding the openings in the shear walls, we examined the following percentages: 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50%. In this study, we chose a specific case where the openings are present in both directions of the L-shaped wall.

Table 1 – Periods according to the soil category.

Soil type	S1	S2	S3	S4
T2 (sec)	0.30	0.40	0.50	0.70

With:
S1: Rocky soil,
S2: Firm soil,
S3: Loose soil,
S4: Very loose soil.

The numerical simulation is carried out according to the Algerian seismic regulation RPA99/V2003 (2003). All the necessary calculation parameters have been fixed, with the only variation being the zone acceleration coefficient, which depends on the type of soil (see Table 1). For the dynamic calculation, we used the response spectrum method. This method involves applying seismic loads using a response spectrum that illustrates the variation of seismic acceleration based on the vibration period of the structure. This allows us to include the dynamic effects of the earthquake on the studied building. It is important to emphasize that the buildings are presumed to be situated in a high-seismicity zone, following the provisions of RPA99/V2003.

3. Building and the variables studied

3.1. Compressive stress

The results that we will discuss concern specifically the shear walls on the ground floor of the building. This zone is particularly important as it experiences high tensile and compressive stress, with a notable concentration of stress at the L-shaped shear wall's band. Additionally, we will examine walls with openings. The results of compression and tensile stress for the shear walls are particularly significant, and consequently, subsequent comparisons will be based on these results. Table 2 summarizes the maximum compression stress obtained for the different analyzed models. As for Figure 1, it illustrates the distribution of compression stress depending on the openings in the shear walls, under the combined effect of permanent, operational, and seismic loads.

The obtained results highlight a progressive increase in compression stress for buildings equipped with openings, reaching a maximum value when the openings represent 50% of the wall's surface. However, it should be noted that these stress decrease with an increase in wall thickness. Walls with a thickness of 15 cm were observed to have the highest maximum stress. This trend was consistently observed for all four types of soils studied. Furthermore, it is interesting to note that changing the soil type from rocky soil to very loose soil results in an increase in compression stress on the L-shaped shear walls. For instance, the 15 cm thick wall with a 50% opening located on S4 soil exhibits a significant increase of 45% compared to the identical building located on S1 soil. The significance of soil type on the compression stress experienced by the shear wall is highlighted by this research. The distribution of stress and how they affect the structural walls of buildings are strongly influenced by soil types. This finding emphasizes the importance of a thorough soil study in the planning and construction of buildings to ensure their durability and stability.

The compression stress on the 15 cm thick shear wall of the building located on soil S1, with a 50% opening, shows an increase of 23% compared to the wall without openings on the same soil. This increase is even more pronounced for walls with a thickness of 20 cm and 25 cm, with respective increases of 28% and 32%. It is observed that the stress difference between the three types of walls decreases as the openings increase. For example, for the 20 cm and 25 cm walls with 50% openings, there is a decrease in compression stress of 2% and 3% respectively compared to the 15 cm wall. We noticed a similar pattern for different soil types, where the same variation in stress was found between walls of 15 cm and 25 cm thickness. This implies that, regardless of the soil type, the effect of wall thickness on compression stress remains constant. Linear equations are proposed between compressive stresses and shear wall opening percentages, and the coefficients of determination obtained are high.

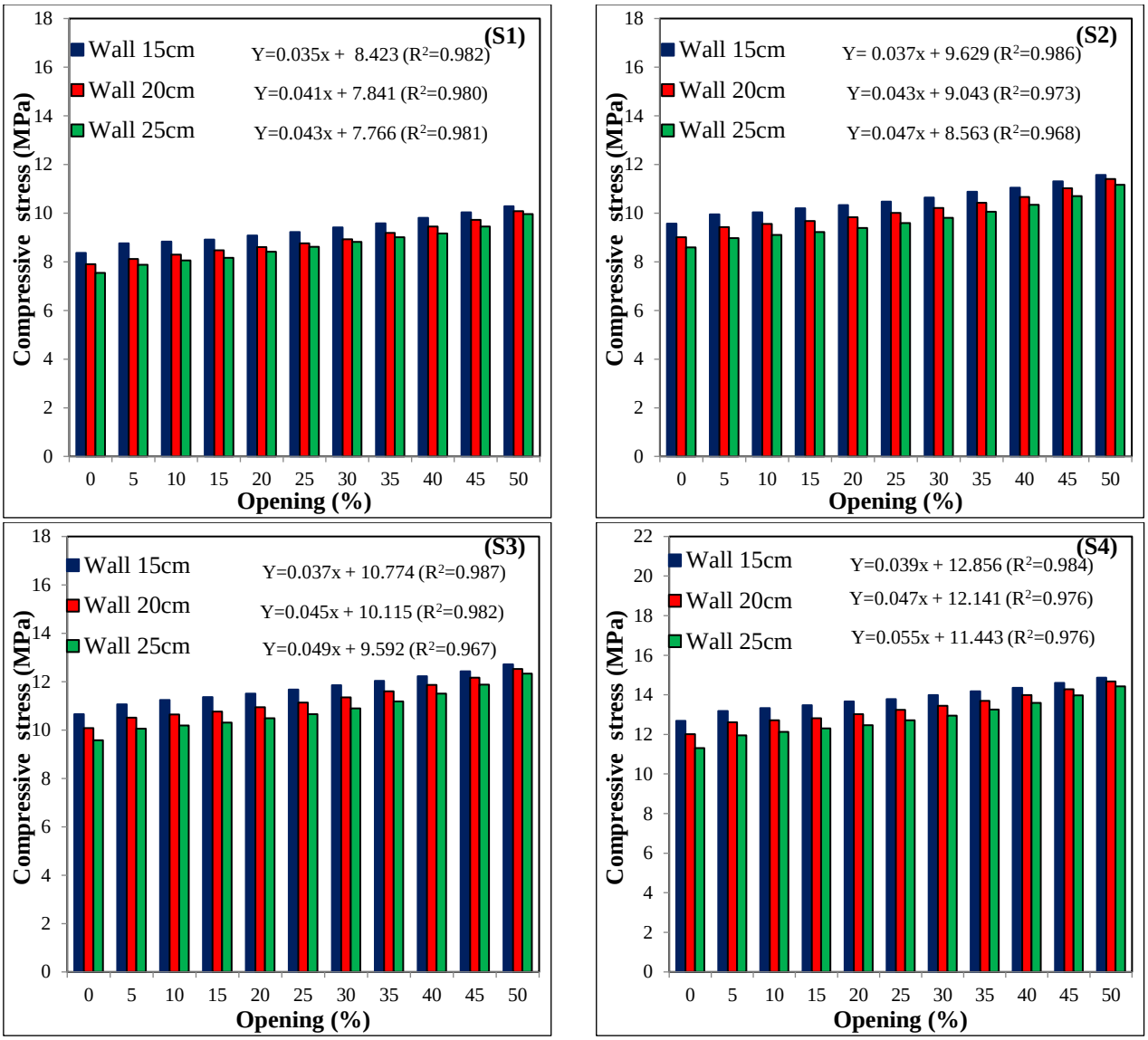


Figure 1 - Variation of compressive stress with apertures according to site type

Table 2 – Compressive stress with the various studied parameters (MPa).

		Openings (%)										
Wall	**Soils**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
15cm	S1	8.37	8.76	8.83	8.91	9.08	9.22	9.41	9.58	9.81	10.04	10.28
	S2	9.57	9.95	10.03	10.20	10.33	10.48	10.64	10.88	11.05	11.31	11.57
	S3	10.65	11.06	11.24	11.36	11.51	11.67	11.85	12.03	12.23	12.43	12.72
	S4	12.69	13.18	13.33	13.48	13.66	13.78	13.99	14.18	14.36	14.60	14.87
20cm	S1	7.90	8.12	8.30	8.47	8.60	8.76	8.93	9.19	9.45	9.73	10.08
	S2	9.01	9.43	9.56	9.68	9.83	10.01	10.21	10.43	10.67	11.02	11.41
	S3	10.08	10.51	10.64	10.76	10.94	11.13	11.35	11.60	11.87	12.17	12.52
	S4	12.01	12.62	12.72	12.82	13.03	13.24	13.45	13.70	13.99	12.28	14.68
25cm	S1	7.55	7.88	8.06	8.16	8.42	8.62	8.82	9.01	9.17	9.45	9.96
	S2	9.01	9.45	9.56	9.68	9.83	10.01	10.21	10.43	10.67	11.02	11.41
	S3	9.58	10.06	10.19	10.31	10.49	10.65	10.90	11.18	11.50	11.88	12.33
	S4	11.31	11.96	12.13	12.31	12.47	12.71	12.95	13.26	13.60	13.98	14.43

3.2. Tensile stress

Figure 2 and Table 3 present the variation of tensile stress for the given buildings based on different openings, wall thicknesses, and soil types. A similar trend is observed for tensile stress, where buildings with higher wall thicknesses and larger openings exhibit lower tensile stress for the same soil type. Conversely, it is observed that these stresses are higher when the soil quality is lower, meaning when the soil stress is weaker.

A notable exception was observed for rocky soil (S1). In this specific case, we notice that walls with a thickness of 25 cm exhibit higher stress with increasing openings in the walls. Additionally, for a 25% opening, an intersection of stress between the 15 cm and 20 cm walls is also observed. From the results found, the 20 cm thick wall recorded lower tensile stress values. This difference can probably be attributed to the specific quality of rocky soil, which can impact stress distribution. However, the overall general trend of stress observed for the four studied soils approaches each other as the openings reach 50% of the wall surface. For example, in the case of S1 soil, the stress difference between the 15 cm and 20 cm walls is 1.10%. Similarly, the stress difference between the 20 cm and 25 cm walls is 2.06%. These values illustrate relatively small stress differences between the different considered thicknesses. Indeed, the results suggest that with 50% openings, tensile stress is nearly the same, regardless of wall thickness and soil type. Compared to compression stresses, the evolution of tensile stress remains minimal, which is beneficial since concrete exhibits better resistance to compression. This indicates that the percentage of openings has a more significant impact on tensile stress than wall thickness or soil type.

The ratio between compressive stress (Rc) and tensile stress (Rt) in shear walls is closely linked to the opening size of these walls. An observation in buildings equipped with 15 cm walls, located in S1, shows that the Rc/Rt ratio starts at 1.42 with a 5% opening, and then gradually increases to 1.61 when the opening reaches 50%. This trend indicates that increasing the opening leads to a predominance of compressive stress over tensile stress. However, the wall thickness also plays a role in this ratio. A decrease in this ratio is observed as the wall thickness increases. This finding holds for all four types of soils studied. Indeed, the type of soil has a significant influence on the Rc/Rt ratio. A decrease in soil quality results in a reduction of this ratio. For example, in the case of a braced building with 25 cm thick walls on a type S4 soil, the Rc/Rt ratio reaches 1.20, highlighting the importance of considering soil characteristics in the design of structures. This study highlights the critical factors influencing the ratio between compressive and tensile stresses in shear walls. The wall openings, wall thickness, and soil type are interdependent parameters that must be carefully considered during the design process. The obtained compression and tensile stress remain below the design limits required by building codes.

A linear correlation analysis was carried out between tensile stresses and opening percentages, as shown in Figure 2. It can be seen that the coefficients of determination are lower than those previously obtained for compressive stresses. In the case of site S1, it is notable that there is no linear correlation between tensile stresses and openings.

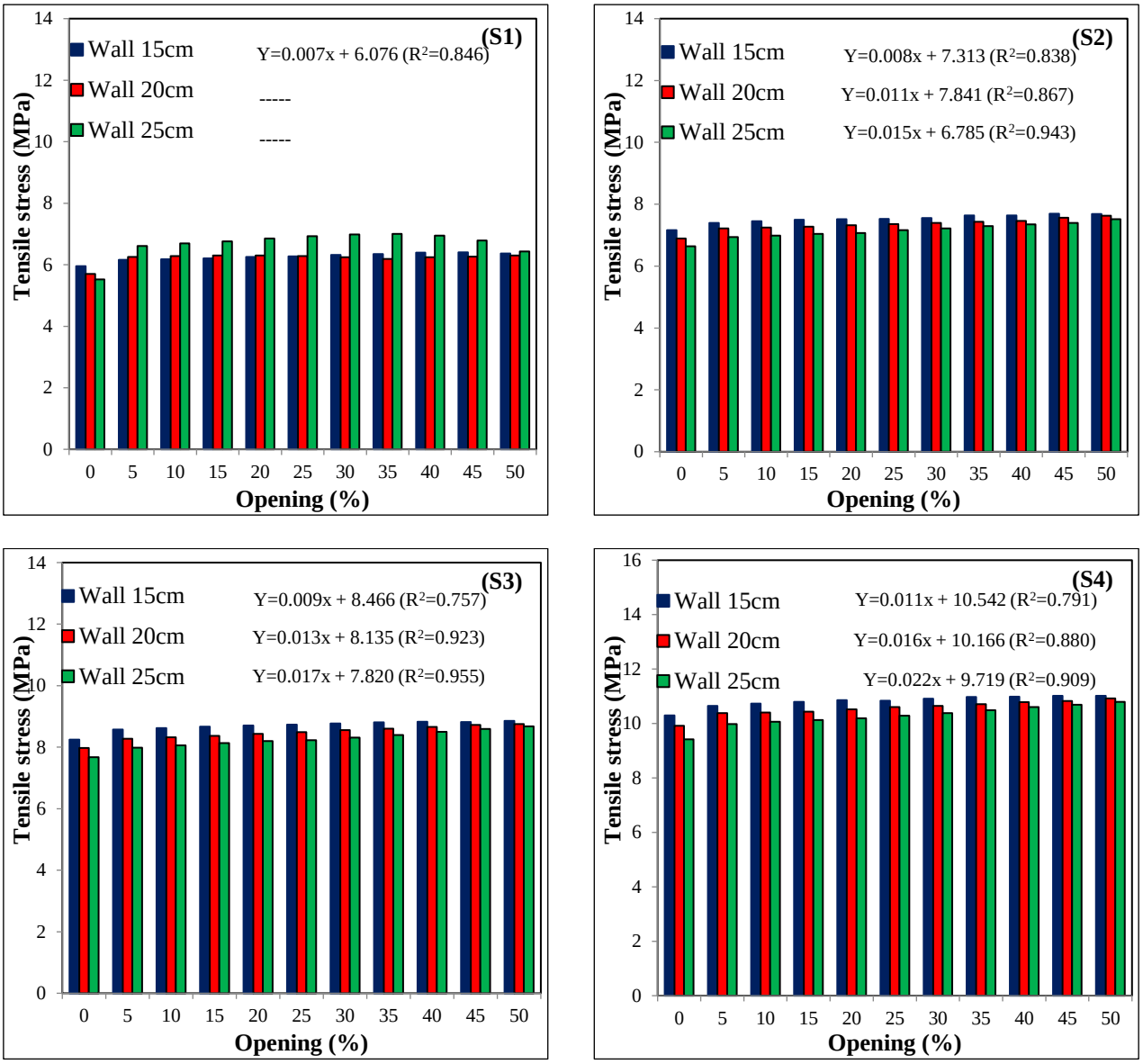


Figure 2 - Variation of tensile stress with apertures according to site type.

Table 3 – Tensile stress with the various studied parameters (MPa).

		Openings (%)										
Wall	**Soils**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
15cm	S1	5.95	6.16	6.18	6.21	6.25	6.27	6.32	6.35	6.39	6.40	6.37
	S2	7.16	7.40	7.45	7.50	7.52	7.53	7.55	7.64	7.64	7.69	7.68
	S3	8.25	8.57	8.62	8.67	8.70	8.73	8.77	8.81	8.83	8.82	8.85
	S4	10.30	10.65	10.73	10.80	10.86	10.84	10.91	10.97	10.99	11.02	11.02
20cm	S1	5.70	6.25	6.28	6.30	6.30	6.28	6.24	6.19	6.24	6.26	6.30
	S2	6.89	7.22	7.25	7.27	7.32	7.36	7.40	7.43	7.46	7.56	7.63
	S3	7.97	8.27	8.32	8.37	8.43	8.49	8.55	8.60	8.66	8.72	8.75
	S4	9.92	10.38	10.40	10.43	10.52	10.60	10.65	10.71	10.78	10.83	10.92
25cm	S1	5.52	6.61	6.69	6.76	6.85	6.93	6.98	7.00	6.95	6.79	6.43
	S2	6.64	6.94	6.99	7.04	7.07	7.16	7.22	7.29	7.35	7.40	7.52
	S3	7.67	7.98	8.06	8.13	8.20	8.23	8.31	8.40	8.50	8.59	8.68
	S4	9.42	9.98	10.06	10.13	10.19	10.29	10.38	10.49	10.60	10.69	10.79

Based on the results presented in Tables 2 and 3, linear equation (1) demonstrates the highest correlation between compressive and tensile stresses, with a coefficient of determination of 0.90. This equation can be considered effective in predicting the stresses of the proposed building models, regardless of the percentage of openings in the shear walls (see Figure 3). On the other hand, equation (2), although showing a correlation of results passing through the origin, displays the lowest coefficient of determination (0.84).

$$R_s = 1.07R_t + 2.14 \quad (1)$$

$$R_s = 1.32R_t \quad (2)$$

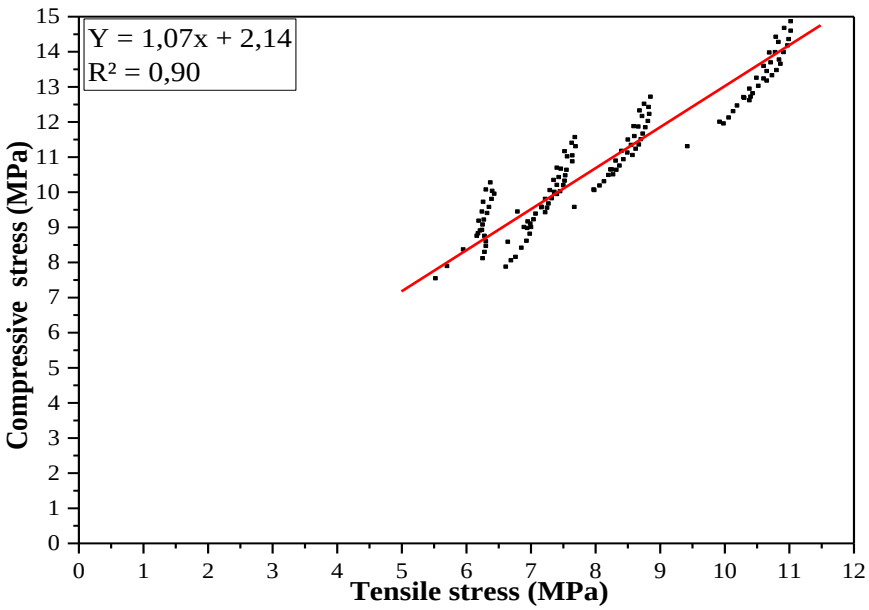


Figure 3- Correlation between compressive and tensile stresses.

3.3. Shear stress

The shear stresses as a function of openings in the shear walls, thickness, and soil type are illustrated in Figure 4 and Table 4. According to this figure, a similar trend of shear stress is observed

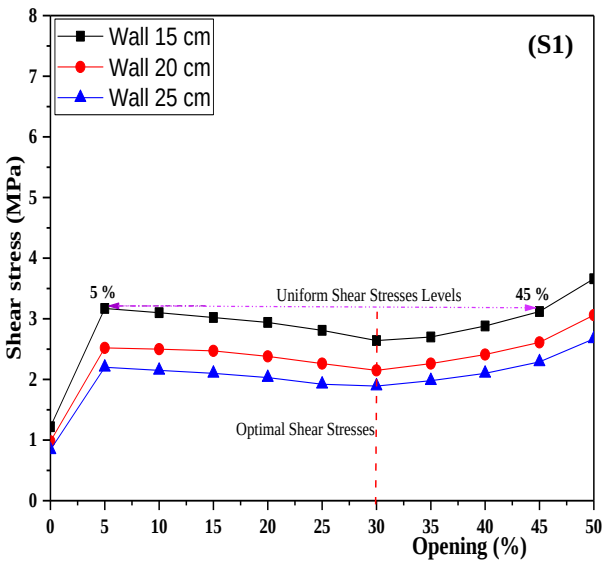
for the four types of soil studied. This applies to all three shear walls, irrespective of shear wall thickness and soil type. On the other hand, this stress is a function of the percentage of openings in the concrete walls.

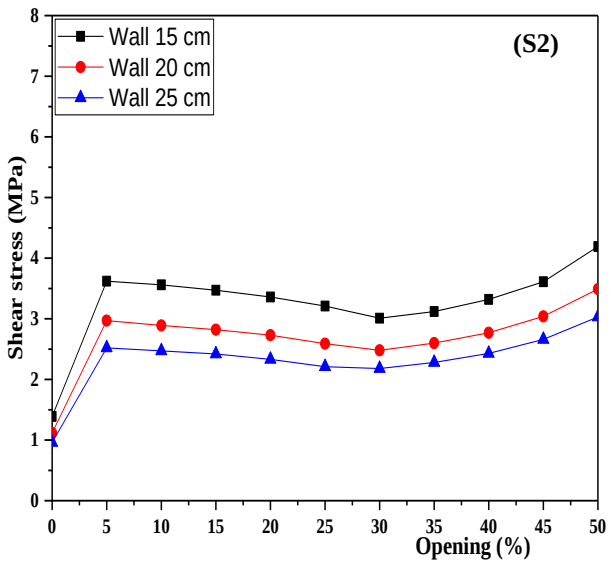
We observe that increasing the thickness of the shear wall reduces the shear stress. When the percentage of openings in the shear wall is minimal, we observe a significant increase in shear stresses around the openings spontaneously. However, unlike the compressive and tensile stress, we find that the shear stress decrease until reaching approximately 30% openings, and then they continuously increase with further openings. This suggests that two openings produce similar shear stress. For instance, a shear wall with 5% openings generates comparable shear stress to that resulting from an opening of around 45%.

The percentage of openings at approximately 30% appears to be optimal for obtaining minimal shear stress. In this case, the walls on both sides of the opening have a Height/Length ratio equal to 2.423, allowing us to calculate web lengths that are 8.25d, 6.13d and 4.952d for web thicknesses of 15, 20 and 25 cm respectively. This allows us to conclude that these walls are subjected to a combination of bending and shear stresses (ASCE 41-17., 2017). Hence, it is important to consider this threshold to maintain low shear stress in the design of shear walls with openings.

The shear stresses in the 20 cm and 25 cm walls of buildings located on soil S1, with 30% openings, are 18.56% and 28.41% lower, respectively, compared to the 15 cm shear wall. This significant decrease in shear stress highlights the benefits of increasing the wall thickness and adding openings to reduce shear stress. The results obtained are consistent for all four types of soil studied. For soil S4, the shear stress decrease by 17.04% for the 20 cm walls and by 27.17% for the 25 cm walls, compared to the 15 cm shear wall.

It is important to note that the maximum recorded shear stress, which occurred on soil S4, was 5.61 MPa for the 15 cm thick wall. This value exceeds the allowable shear stress limit of 5 MPa. An opening of 45% is recommended to ensure the safety of the building, which would result in a shear stress value of 4.95 MPa (Table 4). This percentage of opening would meet the established safety criterion, thus guaranteeing adequate structural performance in terms of shear stress.





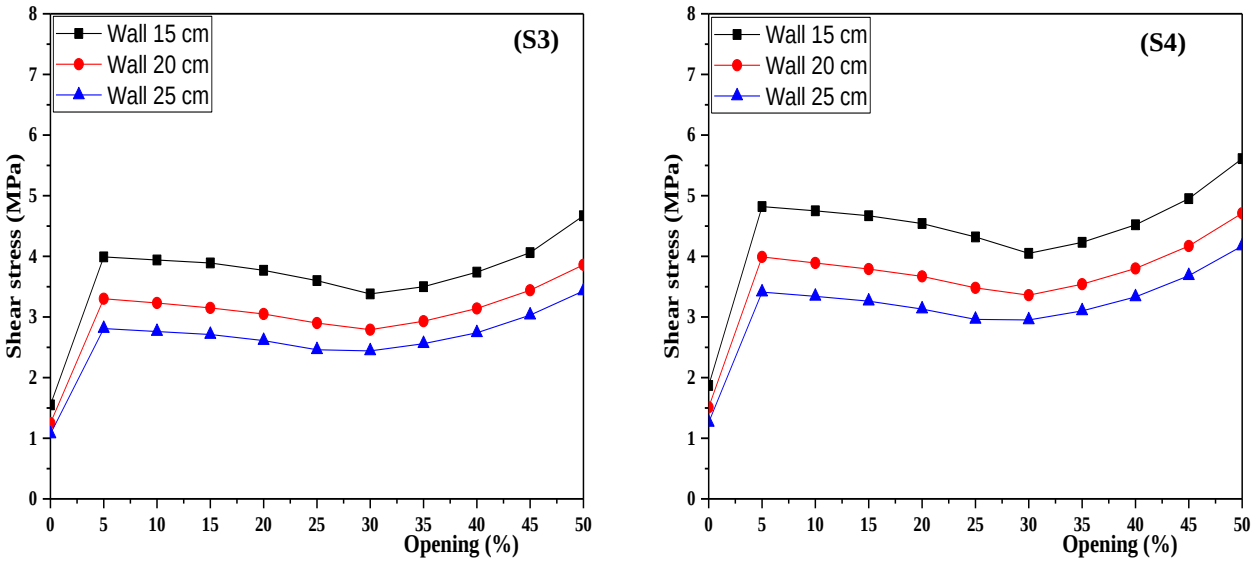


Figure 4- Variation of shear stress with apertures according to site type.

Table 4 – Shear stress with the various studied parameters (MPa).

		Openings (%)										
Wall	**Soils**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
15cm	S1	1.22	3.17	3.10	3.02	2.94	2.81	2.64	2.70	2.88	3.12	3.66
	S2	1.39	3.62	3.56	3.47	3.36	3.21	3.01	3.12	3.32	3.61	4.19
	S3	1.55	3.99	3.94	3.89	3.77	3.60	3.38	3.50	3.74	4.06	4.67
	S4	1.87	4.82	4.75	4.67	4.54	4.32	4.05	4.23	4.52	4.95	**5.61**
20cm	S1	0.98	2.52	2.50	2.47	2.38	2.26	2.15	2.26	2.41	2.61	3.06
	S2	1.12	2.97	2.89	2.82	2.73	2.59	2.48	2.60	2.77	3.04	3.49
	S3	1.25	3.30	3.23	3.15	3.05	2.90	2.79	2.93	3.14	3.44	3.86
	S4	1.51	3.99	3.89	3.79	3.67	3.48	3.36	3.54	3.80	4.17	4.71
25cm	S1	0.84	2.20	2.15	2.10	2.03	1.92	1.89	1.98	2.10	2.29	2.67
	S2	0.96	2.52	2.47	2.42	2.33	2.21	2.18	2.28	2.43	2.66	3.03
	S3	1.07	2.81	2.76	2.71	2.61	2.46	2.44	2.56	2.74	3.03	3.43
	S4	1.26	3.41	3.34	3.26	3.13	2.96	2.95	3.10	3.33	3.68	4.17

3.4. Optimal openings in the wall

Table 5 presents the recommended optimal percentages of vertical openings for the shear walls. These opening percentages were determined while complying with the provisions of the Algerian seismic code. Indeed, this code imposes certain recommendations to be followed during the building's design, such as the period, inter-story displacement, shear force, etc. These parameters are taken into account to ensure adequate seismic resistance of the buildings and to guarantee their safety in the event of an earthquake. The study demonstrated that the percentage of openings is closely related to the thickness of the shear walls and the type of soil. These recommended percentages allow for an optimal design of the shear walls, ensuring both seismic resistance and structural safety.

It was also noted that buildings constructed on very loose soil (S4) cannot incorporate any vertical openings in the shear wall. This is due to the increase in seismic force (Vt) at the base of the building, which increases with the decrease in soil quality. Furthermore, it was observed that the percentage of openings in the walls increases with the increase in the thickness of the shear wall, and rocky (S1) and firm soils (S2) allow for larger vertical openings than loose and very loose soils (S3 and S4). However, it is interesting to note that the percentage of openings in soils S1 and S2 remains the same regardless of the thickness of the shear wall.

In conclusion, the study provides valuable insights into the optimal design of shear walls with vertical openings based on different soil types and wall thicknesses. Following these recommendations will ensure the structural integrity and seismic safety of the buildings.

Table 5 - Openings by soil type and wall thickness.

Soil type	S1	S2	S3	S4
15	29.00	29.00	20.80	-
20	39.60	39.60	34.80	-
25	45.70	45.70	42.20	26.80

4. Conclusion

The following conclusions can be drawn from the analytical study on the effect of openings, soil types, and wall thicknesses on the seismic behavior of shear walls:

- Models of shear walls without openings yielded better results in terms of stress, highlighting the significant effect of using solid walls.
- Compression and tensile stress increase with increasing percentages of openings in shear walls, reaching approximately 14.87 MPa for compression and 11.02 MPa for tensile for 50% of openings, compared to walls without openings.
- The thickness of the L-shaped wall plays a significant role, as thicker walls result in lower compression stresses. Similarly, the type of soil influences the stresses, with soft soils leading to higher stresses. A similar trend is observed for tensile stresses, except for soil type S1, where larger openings in 25 cm thick walls result in higher tensile stresses.
- The shear stress decreases up to 30% of the opening, then increases independently of the wall thickness and soil type, reaching 5.61 MPa for the 15 cm thick wall located in soil type S1. Considering that these shear stresses primarily concentrate around the openings, it necessitates additional reinforcement of the reinforcement bars (rebar) in these areas.
- The percentage of openings is closely related to the thickness of the shear walls and the type of soil. The recommended percentages of openings enable an optimal design of shear walls, ensuring both seismic resistance and structural safety. However, a 30% opening percentage is optimal to maintain minimal shear stresses during the design of shear walls.

The results demonstrate that stresses in structures with L-shaped walls vary depending on the wall thickness, size of openings, and soil type. Other factors may also influence stress distribution. Therefore, conducting further studies is essential to assist engineers in designing even more efficient and secure structures.

References

ACI Committee 318. 318-19. (2022). Building Code Requirements for Structural Concrete and Commentary. American Concrete Institute.

Alarcón, C., López, Á., Vielma, J. C. (2023). Performance of Medium-Rise Buildings with Reinforced Concrete Shear Walls Designed for High Seismic Hazard, Materials, 16, https://doi.org/10.3390/ma16051859.

Alhusban, M., Parvin, A. (2022). Finite Element Analysis of Axially Loaded RC Walls with Openings Strengthened Using Textile Reinforced Mortar for Sustainable Structures, Buildings. 12(11)1993, https://doi.org/10.3390/buildings12111993.

Ashim, A. K., Rao, K. R. M., Gautam, D., Chaulagain, H. (2019). Seismic vulnerability and retrofitting scheme for low-to-medium rise reinforced concrete buildings in Nepal. Journal of Building Engineering, 21, pp.186-199, https://doi.org/10.1016/j.jobe.2018.10.015.

ASCE/SEI 41-17. (2017). Seismic Evaluation and Retrofit of Existing Buildings. American Society of Civil Engineers. Reston, Virginia : American Society of Civil Engineers.

Balkaya, C., Kalkan, E. (2004). Three-Dimensional Effects on openings of laterally loaded pierced

shear walls. J Stru Eng-ASCE.130(10), pp. 1506-1514. https://doi. 10.1061/(ASCE)0733-9445(2004)130:10(1506).

Benbellil, B., Kebdani, S., Kettab, R. M., Benbouras, M. A. (2019). Comparative modelling of seismic performance of L-shaped reinforced concrete shear walls, Urbanism. Arhitectura. Constructii, 10(1). https://creativecommons.g/licenses/by-nc-nd/4.0/.

Bessason, B., Örvar Bjarnason, J. (2016). Seismic vulnerability of low-rise residential buildings based on damage data from three earthquakes (MW 6.5, 6.5 and 6.3).Engineering Structures, 111, pp. 64-79,https://doi.org/10.1016/j.engstruct.2015.12.008.

Berman, J.W., Bruneau, M. (2005). Experimental Investigation of Light-Gauge Steel Plate Shear Walls. Journal of Structural Engineering, 131(2), pp. 259-267, https://doi.org/10.1061/(ASCE)0733-9445.

Chaouch, A. A., Boutemeur, R., Bachtoula, H., Bali, A. (2015). Numerical Study on Shear Stress Variation of RC Wall with L Shaped Section, Periodica Polytechnica Civil Engineering, 59(1), pp. 15-25. https://doi: 10 3311/PPci 7575.

Galal, K., El-Sokkarry, H. (2008). Recent Advancements in Retrofit of Rc Shear Walls, In Proceedings of the 14thWorld Conference on Earthquake Engineering. Beijing, China, pp. 12-17.

Kim, H.S., Lee, D. G. (2003). Analysis of shear wall with openings using super elements. Engineering Structures, 25(8), pp. 981-991, https://doi.org/10.1016/S0141-0296(03)00041-5.

Liu, X.., Zheng, S., Wang, W., Liu, H., Zheng, Y., Zhen, H. (2023). Experimental study on the seismic behaviour of a corroded T-shaped RC shear wall, Journal of Building Engineering, 76, https://doi.org/10.1016/j.jobe.2023.107071.

Mosoarca, M. 2014). Failure Analysis of RC Shear Walls with Staggered Openings under Seismic Loads. Engineering Failure Analysis, 41, pp. 48-64, https://doi.org/10.1016/j.engfailanal.2013.07.037.

Montazeri, E., Panahshahi, N., Cross, B. (2018). Nonlinear Finite Element Analysis of Reinforced Concrete Shear Walls with Staggered Openings under Seismic Loads, Structures Congress: Buildings and Disaster Management.

Najm, H.M., Ibrahim, A.M., Sabri, M. M., Hassan, A., Morkhade, S., Mashaan, N. S., Eldirderi, M.M.A., Khedher, K. M. (2022). Modelling of Cyclic Load Behaviour of Smart Composite Steel-Concrete ShearWall Using Finite Element Analysis, Buildings, 12(6), 850, https://doi.org/10.3390/buildings12060850.

Rong, C., Qu, Y., Shah, A. A., He, H. (2023). Seismic Performance of Energy Dissipation Low Reinforced Concrete Shear Wall with Shear Lead Dampers, Case Studies in Construction Materials, 19, https://doi.org/10.1016/j.cscm.2023.e02276.

Romão, A.A., Costa, E., Paupério, H., Rodrigues, R., Vicente, H., Varum, A. (2013). Costa. Field observations and interpretation of the structural performance of constructions after the 11 May 2011 Lorca earthquake. Eng Fail Anal. 34, pp. 670-692, https://doi.org/10.1016/j.engfailanal.2013.01.040.

Saeed, A., Najm, H. M., Hassan, A., Qaidi, S., Sabri Sabri, M. M., Nuha, S.M. (2022). A Comprehensive Study on the Effect of Regular and Staggered Openings on the Seismic Performance of Shear Walls. Buildings. *12*(9), 1293, https://doi.org/10.3390/buildings12091293.

Sharma, R., Jignesh, A. (2015). Effects of opening in shear walls of 30- storey building. Journal of materials and engineering structures, 2, pp. 44-55.

Ugalde, D., Lopez-Garcia, D. (2017). Behaviour of reinforced concrete shear wall buildings subjected to large earthquakes.,Procedia Engineering, 199(1), pp. 3582-3587. https://doi.org/10.1016/j.proeng.2017.09.524.

Varma, V.N., Kumar, U.P. (2021). Seismic response on multi-storied building having shear walls with and without openings. Materials Today: Proceedings. 37(2), pp. 801-805. https://doi.org/10.1016/j.matpr.2020.05.827.

Wang, Y., Wang, Z., Zhou, Y., Yang, Z., Zhang, Y. (2022). Test and Bearing Capacity Calculation of a New Energy-Dissipated Precast Shear Wall, Buildings, 12(11), https://doi.org/10.3390/buildings12111990.

Xu, G., Zheng, L., Zhou, W., Zhai, C., Wang, D. (2023). Quasi-static tests of squat reinforced concrete shear walls with openings, Engineering Structures, 293, https://doi.org/10.1016/j.engstruct.2023.116666.

Zhou, Y., Zhu, X., Wu, H., Gu, A., Wenbo,T. (2023). Seismic design and engineering practice of a 10-story self-centering precast concrete wall structure, Structural Design of Tall and Special Buildings, https://doi.org/10.1002/tal.2040.